Consideration of sub-annual climate conditions improves understanding of vegetation response to drought in the Southwest

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Introduction

Objective:
To determine vegetation response to the early 21[st] century drought across multiple biomes

Changes in climate

Changes in plant production

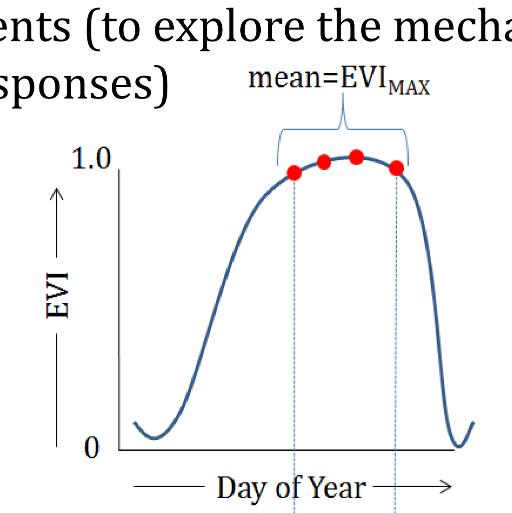
During the early 21[st] century, the Southwest United States has been experiencing a period of prolonged hot drought that is similar to future climate conditions predicted for the region. Understanding how plant productivity, a key ecosystem process, responds to drought is therefore necessary to inform predictions of vegetation response to climate change.

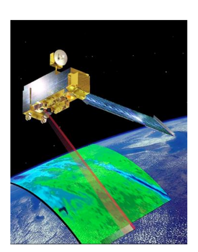
Coupled Approach

Remote sensing observations (to assess interannual variability) were coupled with *in situ* flux measurements (to explore the mechanisms underlying ecosystem functional responses)

Remote Sensing

Vegetation Production: NASA MODIS Enhanced Vegetation Index (**EVI**) served as a proxy for production. EVI_{max} was calculated by smoothing the MOD13Q1 product and then averaging the 4 maximum EVI observations.





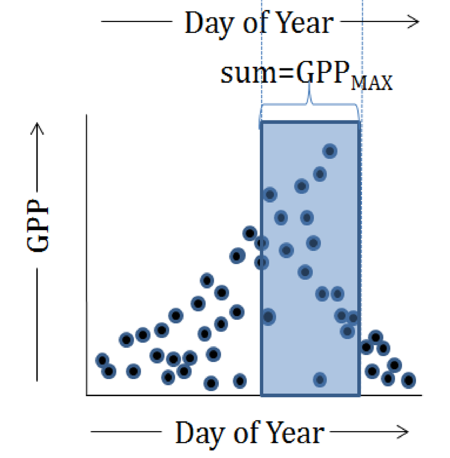
NASA's Terra MODIS

Eddy Covariance Flux Towers

Vegetation Production: Gross Ecosystem production (GEP) is modeled from the following equation:

$$GEP = NEE + R_{eco}$$

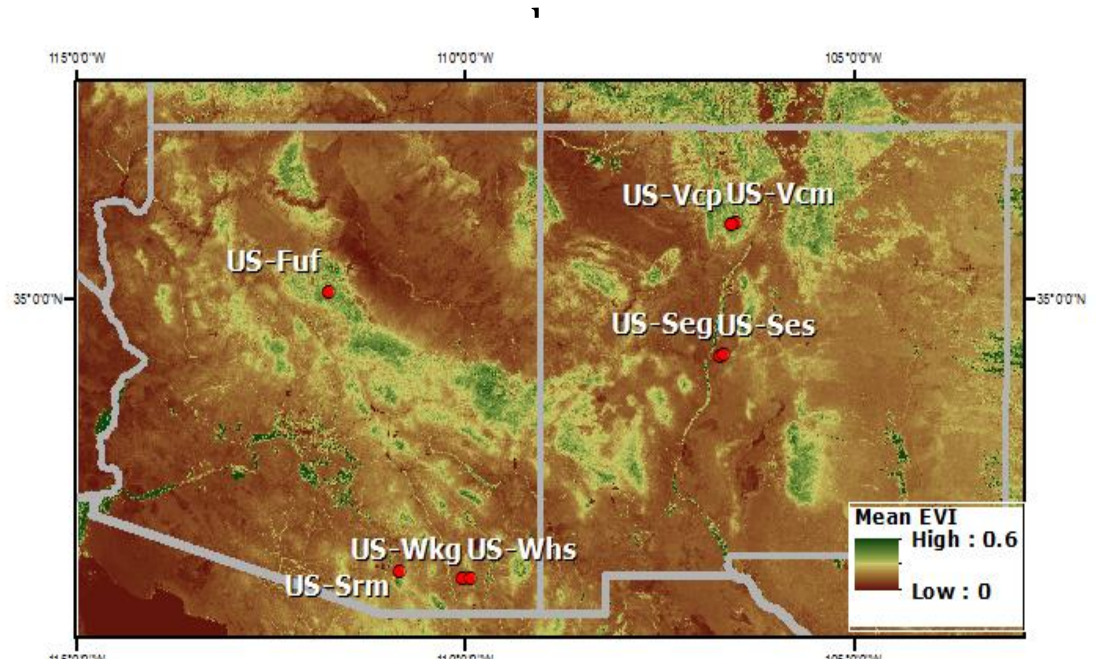
Explored inter- and intra- annual changes in GEP and ecosystem phenology as ecological mechanisms

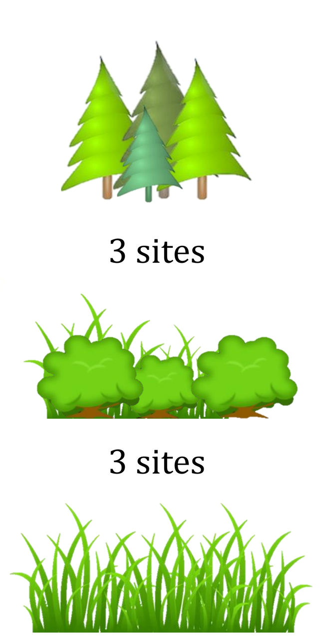


Flux tower at Kendall grassland photo by Russell Scott

Sites

Ten Ameriflux sites across Southwest ecosystem types



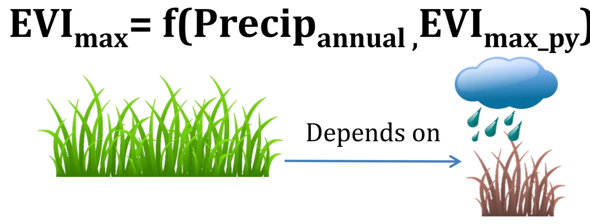


Emipirical Models

Developed biome-specific models of interannual EVI_{max} in relation to annual and sub-annual climatic drivers including precipitation and temperature based on long-term (13-years; 2001- 2013) EVI measurements at each site.

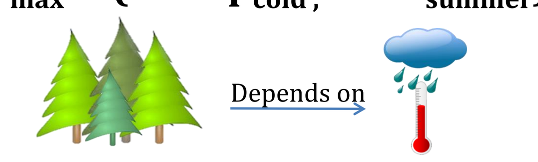
Sala et al. (2012)
Grassland ANPP depends on precipitation in the current year and ANPP in the previous year

Grassland Hypothesis
EVI_{max}= f($Precip_{annual}$, EVI_{max_py})

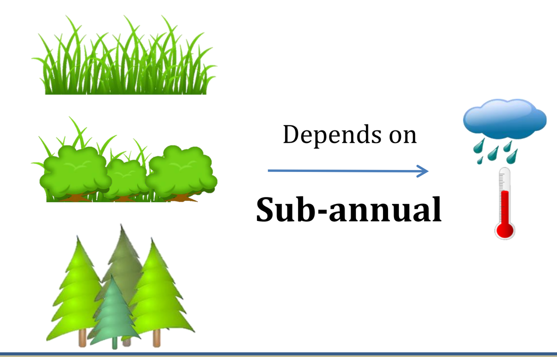


Williams et al. (2013)
Forest Drought-Stress Index depends on cold-season precip and warm season vapor pressure deficit (VPD)

Forest Hypothesis
EVI_{max}= f($Precip_{cold}$, $Tmax_{summer}$)



SPEI
Standardized Precipitation Evapotranspiration Index is a multiscalar drought index that incorporates both precipitation and temperature – ***sub-annual** climate conditions* can be explored.
SPEI was explored in 1 to 12 month timescales calculated back from September, August, and July



Dominant Timescale

The best models were selected based on Akaike's Information Criterion adjusted for small sample sizes (AIC_c) and regression correlation coefficients (r^2). The most parsimonious models for forest, shrublands and grasslands were all based on sub-annual SPEI:

- **Forests**: $SPEI9_{Sep}$ - 9-month SPEI calculated back from September (January – September)
  - $EVI_{maxS(y)} = 0.771(SPEI9_{Sep}) + 0.712$, $R^2 = 0.45$
- **Shrublands**: $SPEI2_{Aug}$ - 2-month SPEI calculated back from August (July & August)
  - $EVI_{maxS(y)} = 0.668(SPEI2_{Aug})$, $R^2 = 0.45$
- **Grasslands**: $SPEI3_{Sep}$ - 3-month SPEI calculated back from September (June-September)
  - $EVI_{maxS(y)} = 0.660(SPEI3_{Sep})$, $R^2 = 0.54$

However, analysis indicated that the combination of precipitation and temperature *during* the dominant timescale, rather than the SPEI itself, predicted interannual variation in EVI_{max}

This suggests that **climate dynamics within the dominant timescale** rather than SPEI itself explained interannual variation in EVI_{max}

Results: Dominant Timescale and Drought

- Forests: $SPEI9_{Sep}$ Production is best determined by 9-month SPEI (Jan - Sep)
- Shrublands: $SPEI2_{Aug}$ Production is best determined by 2-month SPEI (July-August)
- Grasslands: $SPEI3_{Sep}$ production is determined by 3-month SPEI (July-Sep)

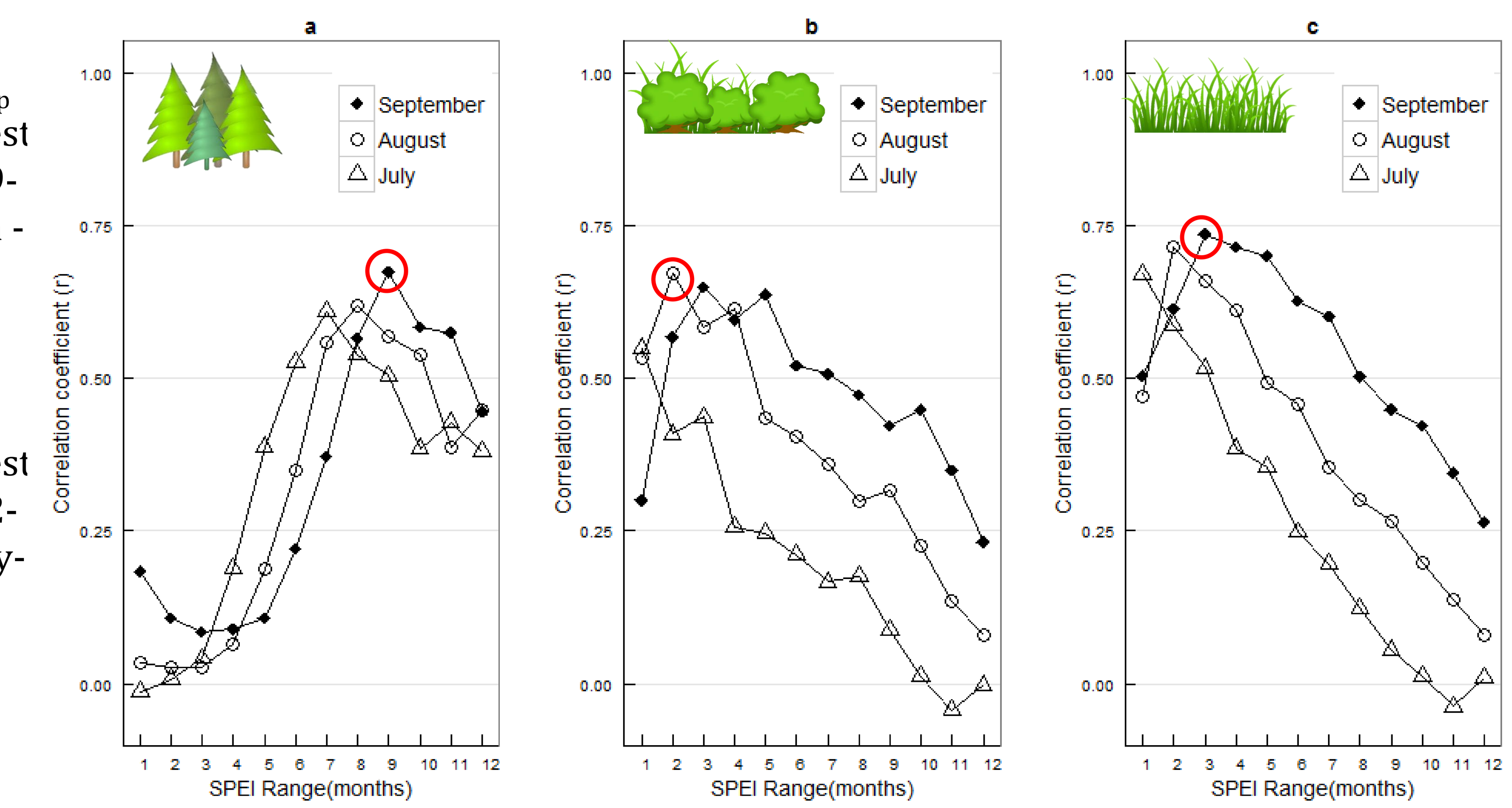


Figure (above): The dynamic timescale of ecosystem response to combined precipitation and temperature (SPEI) for forests (a), shrublands (b), and grasslands (c). Points represent the correlation coefficient r between EVI_{max} and SPEI ranging from one to 12 months, calculated back from July, August, and September.

Drought Revisited

The definition of timescales at which drought has the strongest influence on vegetation production inspired a revisit of the drought conditions at our sites during the early 21[st] century.

Drought is usually quantified at the annual scale

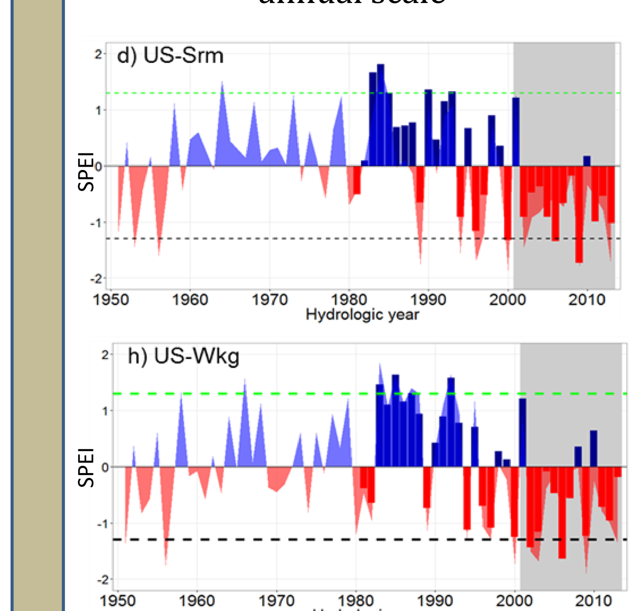
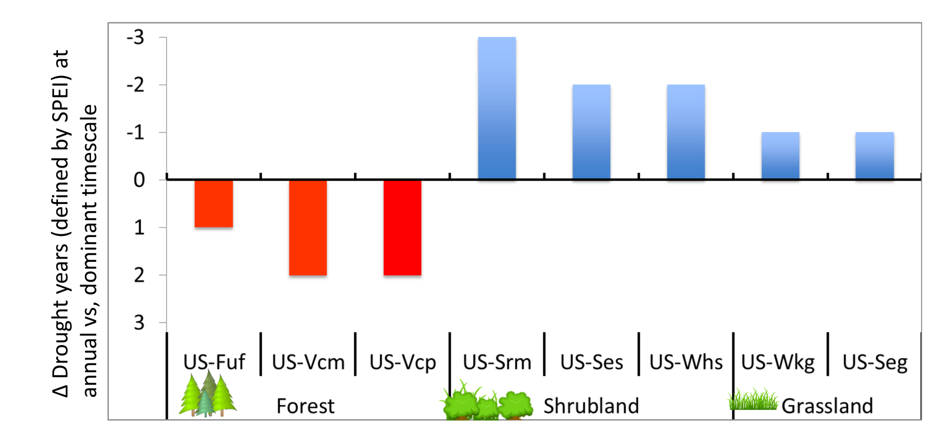


Figure (above): SPEI calculated for Santa Rita and Kendall grassland from 1950-2013. Gray area represents the study period.

Comparing drought conditions during the dominant timescale to annual drought conditions reveals bias:

The number of drought years (SPEI < -0.5) was compared at the annual and dominant timescales (figure, right)



- **Forests**: drought severity underestimated when drought is quantified annually (compared to dominant timescale)
- **Shrublands**: drought severity is overestimated when drought is quantified annually
- **Grasslands**: drought severity is slightly overestimated when quantified annually

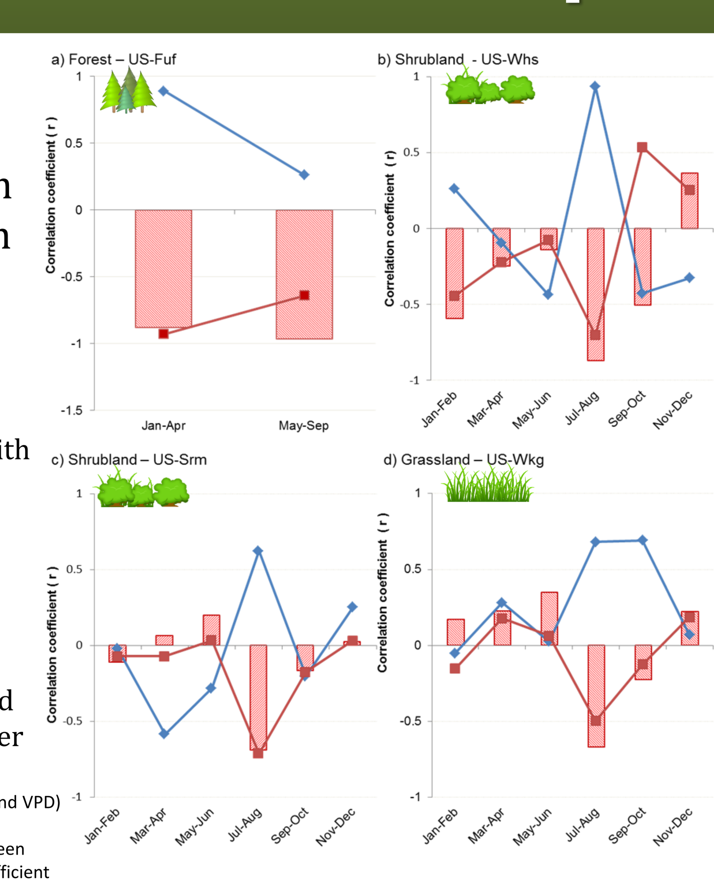
Interpretation and Conclusions

Discerning Mechanisms
Using Flux GEP

Efforts to define mechanisms focused on disentangling the effects of precipitation (P) and temperature (T) during the dominant timescale

- **Forests**: relative importance of P and T shifted throughout the dominant timescale, GEP positively correlated with winter P and negatively correlated with summer T (panel a)
- **Shrublands**: P and T during the monsoon season dominantly influences production, (panel b and c)
- **Grasslands**: production was positively correlated to summer P and negatively correlated with T in July and August, with little effect of T in September and October (panel d)

Figure (to right): The correlation coefficient r between daily climate variables (P, Tmax, and VPD) and standardized maximum GEP (GEP_{maxS}) over different monthly intervals in forests (a), shrublands (b&c), and grasslands (d). Points represent the correlation coefficient r between climate drivers (precipitation and Tmax) and GEP_{maxS}. Bars represent the correlation coefficient between VPD and GEP_{maxS}.



- All biomes had sub-annual dominant timescales during which precipitation and temperature strongly influence on vegetation production
  - Forests: Dominant timescale is 9 months (January – September)
  - Shrublands: Dominant timescale is 2 months (July and August)
  - Grasslands: Dominant timescale is 3 months (July – September)
- Consideration of the dominant timescale improves understanding of how different biomes experience drought
  - Drought severity in Southwest forests is underestimated when only annual precipitation and temperature are considered
  - Drought severity in Southwest shrublands is overestimated
- It is necessary to consider sub-annual climate conditions when assessing drought severity and predicting impacts of future climate change across Southwest biomes

Eddy covariance flux data sources:
Russell Scott, USDA ARS Southwest Watershed Research Center (Kendall Grassland and Lucky Hills Shrubland)
Thomas Kolb, Northern Arizona University (Flagstaff Unmanaged Forest)

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